Are modern varieties always better? An economic analysis of maize varietal selection

Jeffrey J. Reimer*
Department of Applied Economics, Oregon State University, Corvallis, Oregon, USA. E-mail: jeff.reimer@oregonstate.edu

Monica Fisher
International Maize and Wheat Improvement Center, ILRI Campus, Addis Ababa, Ethiopia. E-mail: M.Fisher@cgiar.org

* Corresponding author

Abstract

Numerous high-yielding modern maize varieties have been developed for Malawi. However, their performance and returns when managed under real-world conditions are generally unknown. We have used new cross section data to generate insights into the performance of these maize varieties. We first determined optimal portfolios of maize using expected utility maximisation models under a variety of smallholder preference structures. The analysis revealed a trade-off between expected returns and their variability. Modern varieties are high yielding but also pose relatively more downside risk than traditional varieties, perhaps because they are more sensitive to optimal management conditions. Despite this risk, too many smallholders focus exclusively on traditional varieties, and in particular they exclude any modern variety from their portfolio. Factors inhibiting the adoption of modern varieties were examined econometrically. With respect to policy implications, the results suggest that a mix of modern and traditional varieties could be appropriate for many smallholders, and that extension efforts could target specific groups, such as female-headed farm households of low socioeconomic status, which face severe constraints in the adoption of modern varieties.

Key words: agricultural policy; development; technological change

1. Introduction

Major efforts have been made to develop high-yielding varieties of staple food crops for farmers in sub-Saharan Africa. Despite having expected yields that are generally higher than those of traditional varieties, modern varieties have not always been readily adopted by smallholder farmers (Lunduka *et al.* 2012). A number of reasons have been examined empirically within the literature, including: (a) the local system of land tenure, which may not provide incentives for farmers to innovate; (b) unawareness of new technologies or misconceptions about their benefits and costs; (c) constraints in accessing credit and agricultural inputs; (d) new seed varieties do not meet farmers' criteria for production or consumption characteristics; and (e) farmers are risk averse (Feder *et al.* 1985; Green & Ng'ong'ola 1993; Smale *et al*. 1995; Place & Otsuka 2001; Croppenstedt *et al.* 2003; Doss 2006; Foster & Rosenzweig, 2010; Lunduka *et al.* 2012).

A starting point for much of this literature is that modern varieties can outperform traditional varieties, at least when managed optimally under controlled conditions. However, little is known about their performance in the real world, including whether they are *consistent* in their performance across a broad range of smallholders. Yields of modern varieties are likely somewhat sensitive to proper management, including the optimal application of fertilisers. Even when ideal management is attained, modern varieties may have a broader distribution of returns than tried-and-true local varieties, in part because they are not adapted to the idiosyncrasies of individual sites. The present study examines these possibilities for the case of Malawi.

Malawi makes for an interesting case study on modern maize adoption. As a result of a systematic maize-breeding programme dating back to 1945, a large number of high-yielding hybrid varieties of maize, the staple crop, have been made available to smallholder farmers in Malawi. Considerable effort has been made to inform farmers of at least some of these new maize varieties: for many years, the main focus of agricultural extension in Malawi was to teach farmers about the use and advantages of hybrid maize and inorganic fertilisers (Carr 1997). Furthermore, in Malawi's recent history, prices for hybrid maize seed and chemical fertiliser have been highly subsidised or inputs were distributed for free, except for a few years in the mid-1990s, when agricultural input subsidies were temporarily abandoned as part of structural adjustment. Notably, since 2005/2006, Malawi's Farm Input Subsidy Programme (FISP) has distributed subsidised coupons for modern maize seed and nitrogen fertiliser annually to about half of the country's smallholder maize farmers (Lunduka *et al*. 2013). Despite the Malawi government's efforts to support development and diffusion of modern maize varieties, adoption has remained low (a recent estimate is that less than 40% of national maize area is planted in modern varieties), even for sub-Saharan Africa (Lunduka *et al*. 2012), and our study provides new insights on the issue.

This study examines the performance of modern and traditional maize varieties by drawing on a cross-section dataset, called SIMLESA (Malawi Maize-Legume-based Cropping Systems for Food Security in Eastern and Southern Africa), regarding real-world experiences with maize varieties in Malawi. A wide variation in yield is found, across both varieties and households, and whether one looks within or across agro-ecological zones. Each of the varieties appears to have different strengths and weaknesses, such that there is not a single variety that is superior in all respects all of the time. There appear to be tendencies that are intrinsic to different varieties. Some have high expected yields, for example, while others are relatively robust despite having lower mean yields.

Given these findings, the study addresses several questions: what are the optimal varieties that a smallholder might plant? Is the set of varieties sensitive to different risk preference structures of smallholders? Might there be a single modern variety that is superior in all respects, all of the time, or are there some combinations that work better than others? These questions are addressed through expected utility maximisation as well as alternative optimisation models. Our approach has rarely, or perhaps never, been applied to smallholder agriculture in the way that we do, and we believe that it can be complementary to other farm management tools that have been developed for related contexts (e.g. Dorward 1991).

We examine whether it benefits the smallholder farmer to grow just one maize variety, or diversify and grow a combination of varieties. If the latter is more beneficial, what is the optimal combination? Despite the emergence of interesting new data regarding smallholder agriculture for countries such as Malawi, this type of question has received little attention in the literature. The approach taken here extends early studies such as Saha *et al.* (1994) by considering a developing country context (instead of a developed country context), by considering a much wider range of preference structures than typically considered by the expected utility maximisation literature, and by applying the analysis to the important issue of technology adoption.

We use SIMLESA data from Malawi, which provides cross-section variation in returns, drawing on the experiences of multiple maize-growing households grouped by location. Depending on the smallholder's situation and risk preferences, our results show that an optimal portfolio may include as few as one variety or as many as five varieties.

The second section of the paper compares the recommendations from the expected utility analysis to observed rates of adoption of modern maize varieties by Malawian smallholders. SIMLESA data on farmer rankings of maize varieties with respect to production, vulnerability, post-production and marketing characteristics are used to examine reasons for discrepancies between the recommended portfolios and actual adoption rates. For example, results of the expected utility analysis indicate that the typical smallholder may want to plant at least two varieties of maize to optimize trade-offs between profit, risk and other non-market concerns. However, the household survey data show that, at present, only 31% of farmers grow more than one variety, and only 3% grow more than two. This discrepancy is partly explained by smallholders not being aware of some of the maize varieties, especially those which have minimal trade-offs between profit and risk. Malawian farmers have access to at least twenty-six modern maize varieties, but complete information about all of these varieties has not been available to all producers. The overwhelming number of choices, and unfamiliarity with many varieties, might have hindered the selection of optimal combinations. A number of factors, in addition to incomplete information, might hinder the adoption of modern maize varieties.

The third section of this paper uses a complementary dataset, the Malawi Integrated Household Survey (IHS3), to estimate an econometric model of modern maize adoption to examine factors influencing whether Malawi smallholder farmers are likely to try new varieties. The results show that the following factors influence the adoption of modern varieties: gender, age and education of the plot manager; receipt of information on new seeds; access to capital; receipt of subsidised agricultural inputs; tenure security; market access; and agro-ecological conditions. These results help explain some of the discrepancies we find between optimal portfolios and what farmers actually plant. The results also shed light on how agricultural input subsidy and agricultural extension programmes might be revised usefully. These considerations are discussed in the closing section of the paper.

2. Data

The present study uses two complementary datasets: the 2010/2011 Malawi IHS3 and the 2010/2011 Malawi SIMLESA. The IHS3 dataset has the advantages of a large sample (n = 12 271 households), national representation, and geographic variables (e.g. climate, elevation, distance to input and output markets, agro-ecological zones), but only includes information on maize types (i.e. modern vs. traditional), not varieties (for details on the survey and sampling, see National Statistics Office 2012). The SIMLESA dataset has a smaller sample (n = 1 925 households) and is not nationally representative, but provides detailed information on maize varieties and can be generalised to Malawi's major maize-growing areas. The SIMLESA data were collected by the International Maize and Wheat Improvement Center (CIMMYT) in collaboration with Malawi's Department of Agricultural Research Services (DARS). The surveys were implemented in 16 of Malawi's 28 districts. A multistage sampling procedure was used to select villages from each district and households from each village. The SIMLESA dataset is used for the expected utility maximization (portfolio) analysis, and to describe farmers' awareness and perceptions of maize varieties. The IHS3 dataset is used for econometric analysis of modern maize adoption, providing comprehensive information about adoption determinants that can be generalised to Malawian farmers.

The percentages of maize plots (adoption rate) and maize area (adoption intensity) planted with modern varieties in 2009/2010 were calculated from the SIMLESA data (Table 1). Although smallholder farmers cultivated 26 different modern varieties, only a few of those varieties, along with traditional varieties, dominated both adoption rate and adoption intensity.

Table 1. Maize variety adoption, Malawi 2009/2010 (*n* = 2 725 maize plots)

Variety name	Percentage of maize plots planted in the variety	Percentage of maize area planted in the variety
Traditional maize varieties	34.06	32.79
Modern maize varieties	65.94	67.21
DK 8033	5.91	6.80
DK 8035	5.36	5.59
DK 8053	2.53	2.85
DK 8073	1.00	0.76
MH 26	1.83	1.68
MH 18	9.91	11.28
PAN 53	4.33	4.57
SC 403 (Kanyani)	24.07	22.76
SC 627 (Mkango)	8.29	8.29
Other modern maize varieties	2.72	2.62

Note: Thirty-one percent of farmers grew more than one variety, and 3% grew more than two. Other modern varieties include Bingu, CG7, Chitute, DK 8031, MH12, MH 14, MH 27, MH 36, NSCM 41, PAN 4M-19, PAN 67, PHB 30G33, SC 513, SC 719, ZM 523, ZM 621, and ZM 623.

3. Portfolio model

3.1 Farmer choice of maize varieties

In Malawi, maize is the key food crop and it is made into a porridge called *nsima* that is eaten at most meals. Many smallholders consume much of the maize they grow, and sell the rest at market prices. Although smallholders typically sell only a portion of their maize on the open market, these markets are thick enough to have a price for each variety. In particular, there is a sufficiently large number and volume of transactions involved in price determination such that price would vary little with a small change in the number of transactions. Mean prices are reported at the bottom of Table 2. The mean price of traditional maize was 33.0 MK (Malawi Kwacha) per kilogram in 2009/2010. This exceeded that of modern maize varieties, which ranged from 25.5 to 32.4 MK in 2009/2010. Traditional varieties tend to sell at a higher price than modern varieties because Malawians generally prefer the taste of *nsima* made from traditional maize. In addition, traditional maize is said to produce more flour for a given quantity of grain, have superior food preparation characteristics, and have the potential to store better than modern maize (Smale *et al.* 1995).

As mentioned, the profitability and riskiness of the modern varieties under cultivation by smallholders is something not currently well known. About 66% of Malawi smallholders grew just one variety in the year under study, spread over one or a small number of plots of land. (The latter tend to have more plots: averages are 2.7 plots vs. 1.4 plots. Smallholders growing more than one maize variety also typically have more land than those growing a single variety: average farm sizes are 2.6 vs. 1.8 acres.) We now use the aggregate experiences of a large number of smallholders to shed light on what has and potentially could work well in practice. We set up an expected utility maximisation problem of a representative smallholder (Von Neumann & Morgenstern 1944). Smallholders can respond to risk as well as expected returns and input constraints. As such, expected utility maximisation may explain actual farmer behaviour more accurately than profit maximisation (De Brauw & Eozenou 2011). It can explain why two individuals, faced with the same situation, might respond differently. This approach does not exclude profit maximisation, but includes it as a special case.

Table 2. Average input-output ratios and average input resources

	Traditional maize	DK 8033	DK 8035	MH 18	SC 403 (Kanyani)	SC 627 (Mkango)	Amount available
Fertiliser (kg)	5.7	5.6	5.2	5.9	6.2	6.5	37.5
Seed (unpurchased, e.g. saved) (kg)	1.5	0.7	0.4	0.8	0.4	0.3	2
Seed that was purchased (kg)	0.2	0.8	0.8	0.8	0.8	1.0	2
Labour female (days)	4.9	3.9	3.1	4.6	4.3	4.1	26
Labour male (days)	4.3	3.5	2.7	3.8	3.9	3.6	22
Average yield in kg per acre of land	650.3	758.0	901.9	633.2	680.5	791.7	
Average price received (MK/kg)	33.0	31.6	29.9	32.4	30.8	25.5	

Source: Authors' calculations based on 2011 SIMLESA survey data.

A summary of empirical evidence on farmer risk preferences is presented in Saha *et al.* (1994). Farmer behaviour for many countries is often consistent with constant relative risk aversion (CRRA) or decreasing absolute risk aversion (DARA). Farmers in developing countries, in turn, are generally considered to be more risk averse than those in developed countries, a conclusion consistent with DARA.

Before laying out the models, we defined the terms. We let a variety be indexed alternately by $i=1,...,n$ or $h=1,...,n$. β_{ij} is the return (mean output price times yield for one acre) for variety *i* in location $j=1,...,J$, x_i is the share of land devoted to variety *i*, V_{ih} is a variance-covariance matrix of returns for variety *i* and *h*, a_{ik} is the reported amount of input *k* used to produce one kilogram of *i*, and b_k is the household availability of resource *k*.

Risk aversion is associated with the concavity of the utility function. Below we employ different types of utility functions associated with different preferences and forms of risk aversion. Absolute risk aversion concerns one's risk preferences over absolute amounts of income, and is denoted *ara*. Relative risk aversion concerns one's risk preferences over proportions of one's income, and is denoted *rra*.

As a baseline we first considered *profit maximisation*, represented as:

$$\max_{x_i} \frac{1}{J}\sum_{i=1}^{n}\sum_{j=1}^{J}\beta_{ij}x_i \text{ s.t. } \sum_{i=1}^{n}a_{ik}x_i \le b_k,\ x_i \ge 0\ \forall i,k \tag{1}$$

The problem is to choose the share of land devoted to variety *i* in order to maximise expected returns given technology constraints, subject to the input constraints and non-negativity constraints in (1). The key feature of (1) is that no penalty is awarded to higher variability that may arise with certain varieties.

We next considered the expected utility maximisation with the *power utility* function:

$$\max_{x_i} \frac{1}{1-rra}\sum_{j=1}^{J}\left(\sum_{i=1}^{n}\left(\beta_{ij}x_i\right)\right)^{1-rra} \text{ s.t. } \sum_{i=1}^{n}a_{ik}x_i \le b_k,\ x_i \ge 0\ \forall i,k \tag{2}$$

Note the difference between (1) and (2); there now is a utility function that does not necessarily imply proportional increases in utility when expected returns are higher. The power utility function is important to consider because it allows for both constant relative risk aversion (CRRA) and decreasing absolute risk aversion (DARA). Empirical studies based on actual behaviour have yielded estimates in the range 1 to 3 for the coefficient of relative risk aversion (*rra*). We consider the power utility under the *rra* values of 1.5 and 3 below.

Next we considered expected utility maximisation with the *negative exponential* utility function:

$$\max_{x_i} \sum_{j=1}^{J}\left(-\exp\left[-ara\sum_{i=1}^{n}\left(\beta_{ij}x_i\right)\right]\right) \text{ s.t. } \sum_{i=1}^{n} a_{ik}x_i \le b_k,\ \ x_i \ge 0\ \ \forall i,k \tag{3}$$

This provides constant absolute risk aversion (CARA) and increasing relative risk aversion (IRRA). We consider *ara* values of 0.0001 and 0.001.

The last approach was the *mean-variance* approach:

$$\max_{x_i} \sum_{i=1}^{n}\beta_{ij}x_i - \frac{ara}{2}\sum_{i=1}^{n}\sum_{h=1}^{n}V_{ih}x_i x_h \text{ s.t. } \sum_{i=1}^{n} a_{ik}x_i \le b_k,\ \ x_i \ge 0\ \ \forall i,k \tag{4}$$

This approach typically entails an assumption of normally distributed outcomes to be consistent with the expected utility maximisation hypothesis. This method is also sometimes called the E-V approach, and has its origins in work by Freund (1956) and Markowitz (1959).

Two points about our approach are worth emphasising. Some researchers use historical data to impute the appropriate utility function and values of the risk parameter. By contrast, we do not assume that historical practice among farmers is necessarily optimal. The reason is that no smallholder has experience with *all* of these varieties and all possible combinations. The SIMLESA data used for the analysis correspond to 2009/2010, and a given location as identified in the data for which all varieties were observed serves as a unit of observation. This information provides a way to understand what might be possible, in terms of raising profit or lowering risk, for smallholders in Malawi.

3.2 Model results

Table 2 reports average input-output ratios and average input resources for traditional maize and the five main modern varieties. Traditional maize is relatively input intensive, particularly for labour and non-purchased seed, and gives a low average yield. In comparison, DK 8033 requires less labour and has a higher yield. DK 8035 stands out as a variety with low input requirements, especially for fertiliser and labour, but has a high average yield. MH 18, on the other hand, has higher input requirements than DK 8035 and DK 8033 and the lowest average yield. The amount available, in the rightmost column, serves as the constraint for the representative smallholder farmer that we model.

Table 3 reports the variance-covariance matrix of returns (profits) in the cross-section for 2009/2010. One observation to make here is that the traditional maize variety has the lowest variance (13 135 830) of any of the varieties sampled. The variety DK 8035 has the highest variance (103 737 482). There clearly are dramatic differences in the variance of returns across varieties. The relatively small sizes of many covariances indicate that earnings from the varieties are not necessarily strongly correlated with each other, highlighting the importance of varietal choice for an individual producer.

The results of the suite of expected utility maximisation models show optimal allocation of land to the six principal maize varieties under different assumptions about smallholder behaviour and preferences (Table 4). It should be emphasised that no one case is deemed superior or more realistic than any other. The seven cases that are presented encompass a wide range of potential preferences, and enable comparison of the strengths and weaknesses of the different varieties.

Table 3. Variance-covariance matrix of revenues

	Traditional maize	DK 8035	DK 8033	SC 403 (Kanyani)	MH 18	SC 627 (Mkango)
Traditional maize	13 135 830					
DK 8035	882 245	103 737 482				
DK 8033	8 760 408	3 185 978	43 699 837			
SC 403 (Kanyani)	13 170 825	231 923	2 137 611	36 315 293		
MH 18	10 001 911	9 304 678	1 457 180	20 091 707	34 381 180	
SC 627 (Mkango)	10 507 702	14 507 929	19 643 715	3 729 862	12 227 669	58 533 163

Source: Authors' calculations based on 2011 SIMLESA survey data of reported returns by location.

Table 4. Optimal allocation under different assumptions

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
	Profit max risk neutral	Power (*rra* = 1.5)	Negative exponential (*ara* = 0.0001)	Mean variance (*ara* = 0.0001)	Power (*rra* = 3)	Negative exponential (*ara* = 0.001)	Mean variance (*ara* = 0.001)
Profit (returns) associated with above form of preferences							
Mean (MK/acre)	26 958	26 017	25 543	25 380	24 474	23 502	22 567
St. dev. (MK/acre)	10 185	7 416	6 378	6 112	5 023	4 321	3 422
Coefficient of var. (%)	37.8	28.5	25.0	24.1	20.5	18.4	15.2
Optimal allocation of land under above form of preferences (columns sum to one)							
DK 8035	1.000	0.690	0.534	0.481	0.317	0.350	0.141
DK 8033	0	0.310	0.466	0.519	0.530	0.070	0.156
Traditional	0	0	0	0	0.089	0.482	0.653
SC 403	0	0	0	0	0.063	0.097	0.007
MH 18	0	0	0	0	0	0	0.043
SC 627	0	0	0	0	0	0	0

Source: Authors' calculations using CONOPT non-linear equation solver in GAMS, and 2011 SIMLESA data.
Coefficient of variation is the ratio of the standard deviation to the mean.

One important result stands out immediately: there is a trade-off between expected returns and the standard deviation of returns. Portfolios that offer high expected returns also have high variability in returns. One way to see this is through the coefficient of variation, calculated as the ratio of the standard deviation to the mean level of returns. This is reported in Table 4, and shows the extent of variability in relation to mean of the observations.

Because there is a pattern with respect to this (unexpected) characteristic of the results, we ordered the seven cases according to this trade-off. Case 1 has the highest returns (or profits, a term we use interchangeably), and also the highest coefficient of variation, at 37.8% (Table 4). Portfolios that have relatively low expected returns, meanwhile, typically have low variability in returns. Case 7 has the lowest returns and also the lowest coefficient of variation, at 15.2%. There is a continuum between Case 1, which provides the highest expected returns and highest coefficient of variation, and Case 7, which provides the lowest expected returns and lowest coefficient of variation.

Figure 1 displays the trade-off visually. The vertical bars correspond to the seven cases. The expected return is depicted by a circle. The upper end of the bar is the expected return *plus* one standard deviation. The lower end of the bar is the expected return *less* one standard deviation. The length of the vertical bars declines as one moves to the right, signifying that confidence intervals fall, along with expected returns. Again, we emphasise that this is a characteristic of the data more than of the particular models that are used. Furthermore, different specifications of *rra* and *ara* beyond those considered here do not substantially change the general results.

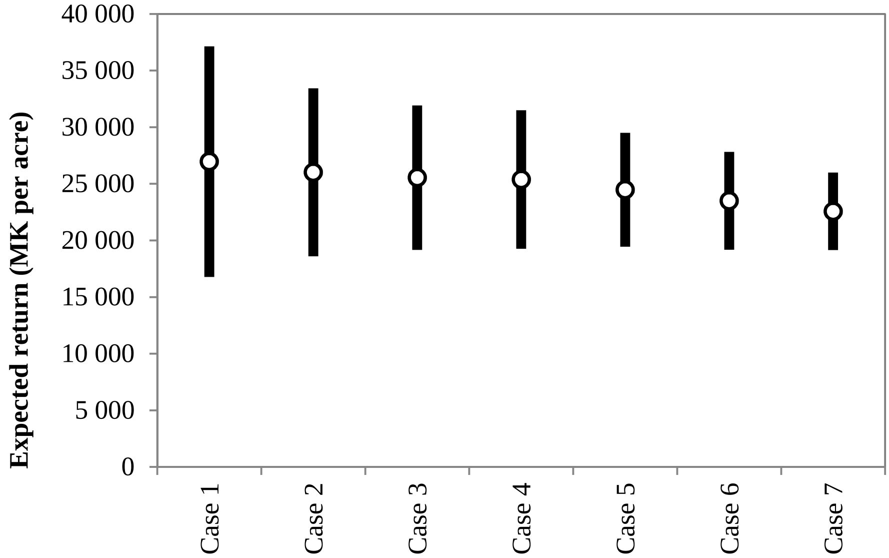

Figure 1. Expected mean return and standard deviation, by case

Turning to Table 4, the situation in which the highest returns can be expected (Case 1) is described first. This is the profit-maximisation, risk-neutral scenario (equation 1). This delivers the highest expected profit (26 958 MK per acre), which is achieved by allocating all land to one variety (DK 8035). Although we noted that DK 8035 has low input requirements, none of the input constraints (seed, labour, fertiliser) in Table 2 are binding in this case; only land is a binding input constraint.

While planting exclusively to DK 8035 provides the highest expected return, it also entails the highest variability in returns. If returns are assumed to be normally distributed (for the sake of illustration), profit would be one standard deviation or more away from the mean about one-third of the time. In this case it would fall below 16 773 MK per acre or exceed 37 143 MK per acre. Note that the majority of this variation may be explained by variation in yield. DK 8035 might be sensitive to the soils, topography and/or climate at the farmer's location. Producers without adequate training or experience with this particular variety might have obtained particularly low yields. Those that happened upon the right set of circumstances received quite high returns, however.

Case 2 concerns the power utility with relative risk aversion equal to 1.5. It provides a somewhat lower expected profit and lower standard deviation (Table 4). Under this form of preferences, variability of returns is now a factor in decision making. Under this setting it is optimal to put 69% of the land in DK 8035 and 31% in DK 8033. This latter variety provides lower variability, with only a small reduction in expected returns.

Cases 3 and 4 concern the negative exponential utility function and the mean-variance (E-V) approach respectively. Both cases assume an absolute risk aversion of 0.0001, which approximates a relative risk aversion value of slightly less than three, if we use the absolute level of returns from the expected profit maximisation problem (Case 1). Similar to Case 2, both cases indicate that it is optimal to divide the acreage between DK 8033 and DK 8035. Case 3 slightly favours DK 8035 (53.4%), while Case 4 slightly favours DK 8033 (51.9%).

The final three cases have successively lower average profits, but also successively lower standard deviations of profit (Table 4). These show that planting DK 8035 and DK 8033 becomes less favourable as the smallholder becomes more risk averse. Case 5 employs the power utility function with a relative risk aversion of three. Model results, once again, suggest planting a combination of DK 8033 (53%) and DK 8035 (31.7%), but combined with another modern variety, SC 403 (6.3%), and a traditional variety (8.9%).

Case 6 employs the negative exponential utility function and assumes an absolute risk aversion of 0.001. The optimal portfolio in this case allocates even more land to the traditional variety (48.2%), with lower proportions to DK 8035 (35.0%), SC 403 (9.7%) and DK 8033 (7%).

Case 7, finally, corresponds to the mean-variance (E-V) approach, with absolute risk aversion of 0.001. More than half of the land (65.3%) is allocated to traditional maize varieties, with smaller shares of DK 8033 (15.6%), DK 8035 (14.1%), MH 18 (4.3%), and SC 403 (0.7%). Although the expected return is only 22 567 MK per acre, much lower than the 26 958 MK per acre of Case 1, the standard deviation is only 3 422, compared to 10 185 in Case 1.

It is clear that smallholders could maximise expected returns by planting all maize land to DK 8035. However, this approach may not be appropriate for the smallholder who is financially vulnerable and worried about downside risk. Planting traditional maize varieties reduces expected returns, but also reduces the variance in returns. Farmers may experience more consistency, since growers are already familiar with their nuances, and the varieties themselves are more robust to idiosyncratic local conditions (soil, growing season, precipitation, sunlight and pests).

It is reasonable to ask whether one of these cases is better at representing the actual risk preferences of smallholders, or for making recommendations. However, our objective has not been to identify any of these cases as "more realistic" or "more optimal" than the others. Existing empirical studies suggest that farmers – especially in developing countries – tend to have high levels of risk aversion, suggesting that Case 5 and above could be most relevant. However, we mainly seek to map out what portfolio works best under different assumptions. This approach led (unexpectedly) to the trade-off between *expected* returns, on the one hand, and *variation* in returns, on the other, that is robust across alternative characterisations of producer behaviour.

Turning back to Figure 1, recall that the upper end of the bar is the expected return *plus* one standard deviation, while the lower end of the bar is the expected return *less* one standard deviation. Observe that the expected value of Case 7 is 16.2% lower than that of Case 1. If we look at the mean less one standard deviation, Figure 1 reveals that it actually rises as we move from Case 1 to Case 7, even though the expected mean is falling. In particular, the mean less one standard deviation is 14.1% higher for Case 7 than for Case 1. This occurs even though Case 1 – the risk-neutral profit-max scenario – has a higher expected value. The point is that there is a potentially large downside risk to portfolios with the highest expected returns.

4. Factors influencing adoption of modern maize varieties

4.1. Farmer knowledge of and attitudes toward maize varieties

A comparison of observed adoption rates, farmer rankings of various characteristics, and expected returns and risks indicate a number of reasons why many farmers grow only one variety of maize, often a traditional one. Traditional maize accounted for a high percentage of planting area in 2009/2010 (Table 1). This is despite the large number of modern varieties available and the recent subsidisation of costs for hybrid maize seed and chemical fertiliser (Lunduka *et al.* 2013). The persistent popularity of traditional maize is partly due to favourable processing and consumption characteristics (Smale *et al*. 1995; Lunduka *et al.* 2012), but might also reflect farmer interest in reducing risk (Table 4).

Knowledge of modern varieties appears also to have a strong influence on adoption rates. SIMLESA data show a wide range of information exposure: 15, 11, 83, 54 and 51% of Malawi farmers had heard of DK 8035, DK 8033, SC 403, SC 627 and MH 18 respectively. MH 18 and SC 403 were not the most preferred modern varieties, yet they were the two most commonly grown. SC 403 and SC 627 also accounted for relatively large proportions of observed planting area, considering that they are not highly competitive in the portfolio analysis (Tables 1 and 4). However, farmers have awareness of and access to these two varieties, and rank them highly (Table 5). SC 403 was a top-ranked variety for early maturity, and SC 627 performed well in terms of water logging and grain and cob size, features that do not show up as useful in our portfolio analysis, which focuses on expected returns, variability in returns, and input constraints. The SIMLESA data indicate that Malawian farmers who reported awareness of a modern variety grew that variety, on average, 60% of the time.

DK 8035 accounted for only 6% of maize area planted in 2009/2010 (Table 1). This is in large part because only 15% of farmers were aware of DK 8035. Of those who have experience with it, the SIMLESA data indicate that this variety is highly rated on the basis of agronomic, vulnerability, post-production and marketing/economic traits (Table 5). DK 8035 had the highest overall score and out-ranked most modern varieties and traditional maize in terms of yield, cob and grain size, drought tolerance, early maturity, and water logging.

Table 5. Farmers' ratings of maize varieties, Malawi 2009/2010

Maize trait	Traditional maize (*n* = 1 550)	DK 8033 (*n* = 216)	DK 8035 (*n* = 221)	MH 18 (*n* = 647)	SC 403 (*n* = 998)	SC 627 (*n* = 416)	Other (*n* = 606)
Agronomic							
Grain yield	[3.55,3.65]	[4.14,4.40]	[4,56,4.73]	[4.31,4.43]	[4.51,4.59]	[4.47,4.60]	[4.39,4.51]
Grain size	[3.67,3.77]	[3.88,4.17]	[4.47,4.65]	[4.14,4.28]	[4.21,4.33]	[4.40,4.54]	[4.28,4.40]
Cob size	[3.54,3.64]	[3.82,4.11]	[4.39,4.60]	[4.13,4.26]	[4.12,4.24]	[4.30,4.45]	[4.20,4.34]
Stover	[3.83,3.93]	[3.94,4.20]	[4.22,4.44]	[4.13,4.25]	[4.15,4.25]	[4.17,4.33]	[4.16,4.30]
Uniform maturity	[3.18,3.30]	[3.68,3.97]	[4.46,4.64]	[4.19,4.32]	[4.41,4.50]	[4.35,4.50]	[4.21,4.34]
Vulnerability							
Disease tolerance	[3.57,3.68]	[3.48,3.77]	[3.73,4.00]	[3.65,3.81]	[3.44,3.57]	[3.66,3.84]	[3.60,3.77]
Pest tolerance	[3.62,3.73]	[3.44,3.75]	[3.68,3.98]	[3.63,3.80]	[3.32,3.47]	[3.59,3.79]	[3.50,3.68]
Early maturity	[2.88,2.99]	[3.57,3.92]	[4.55,4.73]	[4.23,4.36]	[4.56,4.64]	[4.30,4.46]	[4.22,4.37]
Water logging	[3.28,3.40]	[2.85,3.20]	[3.64,3.93]	[3.44,3.61]	[3.33,3.47]	[3.53,3.74]	[3.36,3.55]
Drought tolerant	[3.43,3.55]	[3.36,3.64]	[3.86,4.11]	[3.65,3.80]	[3.69,3.81]	[3.66,3.84]	[3.61,3.78]
Post-production							
Storage	[4.49,4.57]	[3.72,4.02]	[3.64,3.93]	[3.80,3.94]	[3.09,3.24]	[3.54,3.73]	[3.64,3.82]
Taste	[4.38,4.46]	[3.97,4.22]	[4.17,4.39]	[4.17,4.29]	[3.95,4.07]	[3.96,4.13]	[4.00,4.15]
Nutrition	[4.17,4.27]	[4.14,4.37]	[4.31,4.53]	[4.21,4.34]	[4.13,4.25]	[4.11,4.29]	[4.15,4.30]
Economics							
Marketability	[4.31,4.39]	[4.12,4.37]	[4.11,4.32]	[4.12,4.25]	[3.91,4.03]	[4.03,4.19]	[3.92,4.07]
Output price	[3.99,4.09]	[3.57,3.84]	[3.96,4.20]	[3.94,4.07]	[3.78,3.91]	[3.80,3.98]	[3.77,3.92]
Overall	[3.80,3.89]	[4.01,4.27]	[4.42,4.58]	[4.21,4.33]	[4.22,4.31]	[4.18,4.32]	[4.11,4.26]

Notes: These are 95% confidence intervals for farmers' average ratings of maize varieties for agronomic, vulnerability, marketing and consumption traits, Malawi 2009/2010. 1 = very poor, 2 = poor, 3 = average, 4 = good, 5 = very good.

4.2. Cash and supply constraints

In the 40% of cases where a modern maize variety was known, but never grown, by a farmer, in some cases a role was played by lack of cash or credit (33%) and/or unavailability of seed (30%). The Malawi Farm Input Subsidy Programme (FISP) was designed to provide relief from both of these constraints. The FISP entitled a beneficiary household to 2 to 5 kg of modern maize seed for free and two 50 kg bags of fertiliser at a 64 to 95% subsidy (Lunduka *et al.* 2013). Of the 26 modern maize varieties cultivated by Malawian farmers in 2009/2010, however, only MH 18, SC 403, SC 627, PAN 67 and DK 8033 were available for FISP coupon redemption in southern Malawi (Lunduka *et al*. 2012). In central and southern Malawi, only 11 maize varieties were obtained with FISP coupons, with SC 403 and SC 627 accounting for about 70% (Holden & Mangisoni, 2013). Thus, supply constraints in the FISP, and perhaps in the overall market, might have had a greater influence than farmer preference on the maize varieties planted.

5. Empirical model of factors influencing adoption of modern maize

We used an empirical adoption model to further examine factors influencing the adoption of modern maize in Malawi. Although we were particularly interested in DK 8035 and DK 8033, the model examines the adoption of modern maize, in general, for several reasons. First, a major point of the earlier analysis is that farmers might do well to add a modern variety alongside the planting of a single traditional variety. Aside from differences in farmer awareness and attitude, and availability of seed access, we expected adoption of modern varieties to be influenced by similar factors. Another consideration is that empirical data on the adoption of DK 8035 and DK 8033 is available for only 300 plots, which may result in small-sample bias (King & Zeng 2011).

5.1 The model

The relationship between the rate of modern maize adoption, A, and a set of explanatory variables is defined by a logit model (equation 5).

$$A = \alpha_0 + \theta \boldsymbol{I} + \delta \boldsymbol{P} + \gamma \boldsymbol{H} + \mu \boldsymbol{L} + \beta_1 T + \beta_2 C + \boldsymbol{\varepsilon} \quad (5)$$

The dependent variable, A, is a binary variable indicating whether or not modern maize is cultivated on the farm plot. The explanatory variables are based on reviews of the adoption of agricultural technology in low-income settings (Feder *et al*. 1985; Doss 2006; Foster & Rosenzweig 2010).

Vector $\boldsymbol{I}$ denotes characteristics of the plot decision maker: binary variables for whether or not the plot manager was a female householder or a wife (male householder is the reference category); variables for the age and education of the plot decision maker; and a binary variable for whether or not the plot manager was from outside the district of current residence. $\boldsymbol{P}$ represents plot attributes: area; a binary variable to indicate the plot's tenure was leasehold or freehold; and the plot's market value, estimated by the respondent.

The household-level factors, $\boldsymbol{H}$, include variables for labour supply; access to cash or credit; and access to information about new seeds from government agricultural extension officers, other farmers, or electronic media. The cash-access variable uses principal component analysis (Filmer & Pritchett 2001), based on components of household ownership of physical assets, access to utilities and infrastructure, and housing characteristics. The credit variable indicates whether household members were denied credit or did not seek credit in the past year, because they believed they would be refused, did not know any lender, had inadequate collateral, or considered borrowing too costly.

The location factors, $\boldsymbol{L}$, include a variable for distance to the nearest major road, to measure market access; and agro-ecological zone binary variables, total precipitation in the last year and elevation of the village, which reflect growing conditions. Explanatory variable, $\boldsymbol{T}$, specifies the 2008/2009 agricultural year to account for differences in adoption rates between the two years covered by the 2010/2011 LSMS.

Variable $\boldsymbol{C}$ is the monetary value of maize seed and fertiliser coupons redeemed by the farm plot decision maker as part of the FISP. Coupon redemption is potentially endogenous and a control function approach is used to test and control for endogeneity bias. Residuals are first estimated using a tobit regression of C on all exogenous variables and suitable identifying instruments. The residuals are included as an explanatory variable in the logit adoption model, and their statistical significance provides a test for endogeneity. Following Ricker-Gilbert and Jayne (2011), we use an instrument with a binary variable indicating a Member of Parliament (MP) resided in the community. There might have been some political influence on allocation, but the MP variable is not expected to directly affect the decision of what type of maize to cultivate. The second identification variable is the number of months the plot manager was away from the village during the previous year. A farmer who was away for more months was less likely to be present to receive a coupon, but absenteeism probably had no direct influence on adoption of modern maize, as long as family members or hired labour were available to cultivate the plot.

5.2 Model results

The results of the logit model (Table 6) are generally consistent with the results of previous research. In terms of decision-maker and household-level factors, female farmers have a lower probability of growing modern maize than male farmers, and older farmers are less likely to grow modern maize than younger farmers. Farm plot managers with a primary school education or higher are more likely to grow modern maize than less-educated farmers, indicating that educated individuals process information about new technologies more quickly and effectively (Foster & Rosenzweig 2010).

Table 6. Logit regression explaining adoption of modern maize seed on maize plots

Variable	Marginal effect	*z*-value
Characteristics of plot decision maker		
Female head	-0.0596	-4.39
Wife in MHH	-0.0525	-2.11
Age (years)	-0.0036	-10.37
Primary education or higher	0.0483	3.61
From outside the district	0.0460	3.41
Plot characteristics		
Area (acres)	-0.0007	-0.76
Freehold or leasehold tenure	0.0714	2.33
Estimated market value (US$ 1 000)	0.0174	2.51
Household-level variables		
Number of female adults (15-64 years)	0.0057	0.71
Number of male adults (15-64 years)	0.0221	3.17
Number of children (6-14 years)	0.0137	3.25
Wealth poor (bottom 40% of wealth-index distribution)	-0.0609	-5.45
Non-labour income last year	0.0207	1.61
Limited access to credit	-0.0226	-2.06
Information on new seed from govt. extension, last year	0.0665	4.61
Information on new seed from other farmers, last year	0.1446	5.05
Information on new seed from electronic media, last year	0.0263	1.35
Locational factors		
Household distance to nearest major road (km)	-0.0033	-6.28
Total precipitation (mm), last year	0.0004	7.51
Elevation (m)	-0.0001	-2.24
Tropic-warm/semiarid AEZ	0.1196	4.84
Tropic-warm/sub-humid AEZ	0.1559	6.51
Tropic-cool/semiarid AEZ	0.1031	4.01
Agricultural year 2008/09	-0.0453	-3.00
Observed value of coupons redeemed (US$)	0.0010	8.86

Note: Because the unit of analysis was the maize plot, standard errors were adjusted for within-cluster (household) correlation, using the household identifier variable. Number of observations was 11 221.

The model results indicate that tenure security, e.g. having freehold or leasehold tenure on a plot, was positively associated with the adoption of modern maize (Table 6). There also was a greater tendency to grow modern maize on plots that farmers subjectively rated as high quality. Thus, farmers with strong rights to good agricultural land appear to have greater incentive to invest in the knowledge required to adopt new seed varieties (Place & Otsuka 2001).

Households that have more adult male and child members have a higher probability of growing modern maize (Table 6). Plots are less likely to be planted with modern maize if they are managed by an individual from a household that is wealth poor and has limited access to credit. The adoption of modern varieties is also influenced by transmission of information from farmer to farmer and from government extension agents.

Poor market access increases a farmer's production costs, reduces profits, and therefore should reduce the adoption of new technologies. As expected, distance to the nearest major road is negatively associated with the adoption of modern maize (Table 6), confirming the results of previous studies (Zeller *et al*. 1998). Plots in localities with favourable growing conditions – relatively high rainfall and low elevation – are more likely to be planted with modern maize. The binary variables for agro-ecological zone are all positive and statistically significant, indicating that modern maize adoption is less likely in the tropic-cool/sub-humid zone (the reference category) than in other agro-ecologies.

Modern maize adoption was higher in 2009/2010 than in 2008/2009 (Table 6). Adoption of modern varieties is positively associated with use a FISP coupon: probability increased by 28% with the use of a complete FISP coupon package. Agricultural input subsidies had a similarly strong positive influence on the adoption of modern maize in Zambia (Smale & Mason 2012).

The residual from the tobit model for coupon redemption is statistically insignificant (p = 0.264) in the logit adoption model and therefore was not included in the final model estimating maize adoption. The lack of statistical significance of the residuals indicates that coupon redemption is exogenous in the adoption model, conditional on the control variables.

6. Conclusions and recommendations

This study uses a three-pronged approach to shed light on the economics of maize production in Malawi. First, a suite of expected utility maximisation and alternative optimisation models were used to compare expected returns and variability of returns for different portfolios of modern and traditional varieties. Portfolios that were optimal under a range of conceivable grower risk preferences were then compared with producer attitudes toward, and actual adoption rates of, modern varieties. Finally, factors that constrain Malawi smallholders from diversifying into modern varieties were examined using econometric analysis.

One of the most striking aspects of the results is the clear trade-off between expected returns, on the one hand, and variability in returns, on the other, that exists across portfolios that have been optimised for different preference structures. There is nothing preordained about this outcome; it is an artefact of the data that likely would not be apparent without the use of portfolio theory and an expected utility maximisation framework.

If a smallholder's goal is to maximise expected returns, without consideration of risk and other factors, there is a single variety to recommend: DK 8035. There is large variation in the returns of this variety, however, since a fair proportion of smallholder farmers had a less-than-stellar overall experience with it, as well as with some of the other modern varieties. The implication is that financially vulnerable households should not necessarily be encouraged to adopt this variety exclusively without careful consideration. The general result of the models developed in the study that incorporate risk aversion recommend a mix of modern varieties and traditional (local) maize. The latter has lower expected returns, but less variability, and therefore can add stability.

A review of planting data indicated that the maize varieties actually grown by Malawian farmers are much less diverse than most of the optimised portfolios, as most farmers plant traditional maize exclusively. Factors that influence the adoption of modern varieties include gender, age and education of the plot manager; receipt of information on new seed; access to capital; receipt of subsidised agricultural inputs; plot size; tenure security; market access; and agro-ecological zone. However, low adoption rates of modern varieties, including DK 8035, are largely attributable to lack of farmer awareness and lack of seed availability by FISP coupon redemption, rather than farmer preference or agro-ecological zone. Thus, there is a need for increased agricultural extension efforts to provide information about modern varieties, particularly about new seed received from government agents and other farmers.

Including the recommended modern varieties in the FISP should also enhance adoption rates by introducing many farmers to new seed and enabling them to gain experience with the varieties in a low-risk setting. Political imperatives suggest that the FISP will continue for the foreseeable future, despite its high fiscal cost. However, the results of the present study also emphasise the need for agricultural policies to be appropriate for agro-ecological and market conditions. For example, even modern varieties are unlikely to be profitable in areas where growing conditions are unfavourable for maize (e.g. high elevation, low rainfall), and farm households distant from agricultural markets will continue to have difficulties accessing modern seed. Finally, the econometric results suggest that agricultural extension efforts and agricultural subsidy programmes might benefit by targeting specific groups, such as female-headed farm households of low socioeconomic status, which face severe constraints to the adoption of modern varieties.

Acknowledgements

We appreciate the comments from the anonymous reviewers and from attendees at the Agricultural and Applied Economics meetings, Minneapolis, USA, July 2014.

References

Carr SJ, 1997. A green revolution frustrated: lessons from the Malawi experience. African Crop Science Journal 5: 93–8.

Croppenstedt A, Demeke M & Meschi MM, 2003. Technology adoption in the presence of constraints: The case of fertilizer demand in Ethiopia. Review of Development Economics 7: 58–70.

De Brauw A & Eozenou P, 2011. Measuring risk attitudes among Mozambican farmers. HarvestPlus Working Paper 6.

Dorward A, 1991. Integrated decision rules as farm management tools in smallholder agriculture in Malawi. Journal of Agricultural Economics 42: 146–59.

Doss CR, 2006. Analyzing technology adoption using microstudies: Limitations, challenges, and opportunities for improvement. Agricultural Economics 34: 207–19.

Feder G, Just RE & Zilberman D, 1985. Adoption of agricultural innovations in developing countries: A survey. *Economic Development and Cultural Change* 33: 255–97.

Filmer D & Pritchett L, 2001. Estimating wealth effects without expenditure data - or tears: An application to educational enrollments in states of India. Demography 38: 115–32.

Foster AD & Rosenzweig MR, 2010. Microeconomics of technology adoption. Annual Review of Economics 2: 395–424.

Freund RJ, 1956. The introduction of risk into a programming model. Econometrica 24: 253–63.

Green DAG & Ng'ong'ola DH, 1993. Factors affecting fertilizer adoption in less developed countries: An application of multivariate logistic analysis in Malawi. Journal of Agricultural Economics 44: 99–109.

Holden S & Mangisoni J. 2013. Input subsidies and improved maize varieties: What can we learn from the impacts in a drought year? Working Paper, Centre for Land Tenure Studies, Norwegian University of Life Sciences, Norway.

King G & Zeng L, 2011. Logistic regression in rare events data. Political Analysis 9: 137–63.

Lunduka R, Fisher M & Snapp S, 2012. Could farmer interest in a diversity of seed attributes explain adoption plateaus for modern maize varieties in Malawi? Food Policy 37: 504–10.

Lunduka R, Ricker-Gilbert J & M, 2013. What are the farm-level impacts of Malawi's Farm Input Subsidy Program? Agricultural Economics 44: 563–79.

Markowitz H, 1959. Portfolio selection: Efficient diversifications of investments. New York: John Wiley & Sons.

National Statistics Office (NSO), 2012. Malawi Third Integrated Household Survey (IHS3) 2010-2011, Basic Information Document. Available at http://siteresources.worldbank.org/INTLSMS/Resources/3358986-1233781970982/5800988-1271185595871/IHS3.BID.FINAL.pdf (Accessed 5 May 2014).

Place F & Otsuka K. 2001. Tenure, agricultural investment, and productivity in the customary tenure sector of Malawi. Economic Development and Cultural Change 501: 77–100.

Ricker-Gilbert J & Jayne TS, 2011. What are the enduring effects of fertilizer subsidies on recipient households? Staff Paper 2011-09, Department of Agricultural Food and Resource Economics, Michigan State University, USA.

Saha A, Shumway CR & Talpaz H, 1994. Joint estimation of risk preference structure and technology using Expo-Power Utility. American Journal of Agricultural Economics 76: 173–84.

Smale M & Mason N, 2012. Demand for maize hybrids, seed subsidies, and seed decision makers in Zambia. HarvestPlus Working Paper, 8. Available at http://www.harvestplus.org/publications/14 (Accessed 10 April 2013).

Smale M, Heisey P & Leathers H, 1995. Maize of the ancestors and modern varieties: The microeconomics of high-yielding variety adoption in Malawi, Economic Development and Cultural Change 43: 351–68.

Von Neumann J & Morgenstern O, 1944. Theory of games and economic behaviour. Princeton NJ: Princeton University Press.

Zeller M, Diagne A & Mataya C, 1998. Market access by smallholder farmers in Malawi: Implications for technology adoption, agricultural productivity and crop income. Agricultural Economics 19: 219–29.